



# NEW MILLENNIUM PROGRAM

## Earth Science Enterprise Technology Planning Workshop

### Large Microwave and Millimeter Wave Antennas

**David Crisp**

**April 13, 2000**



# Agenda



8:30	Program Overview, Objectives, Approach	D. Crisp
8:50	Flight Validation Justification	D. Crisp
9:00	Science capability needs	R. Kakar E. Njoku E. Im
10:00	Break	
10:15	Relevant advanced technologies	C. Moore J. Huang
11:15	Identify convergence of Science Needs and Technology Availability	D. Crisp + All
11:45	Summary of Results	D. Crisp
12:00	Lunch	
1:00	Design candidate validation flights	All
2:30	Break	
2:45	Create Draft Charts	All
4:45	Summary of Progress and next steps	D. Crisp
5:00	Adjourn	

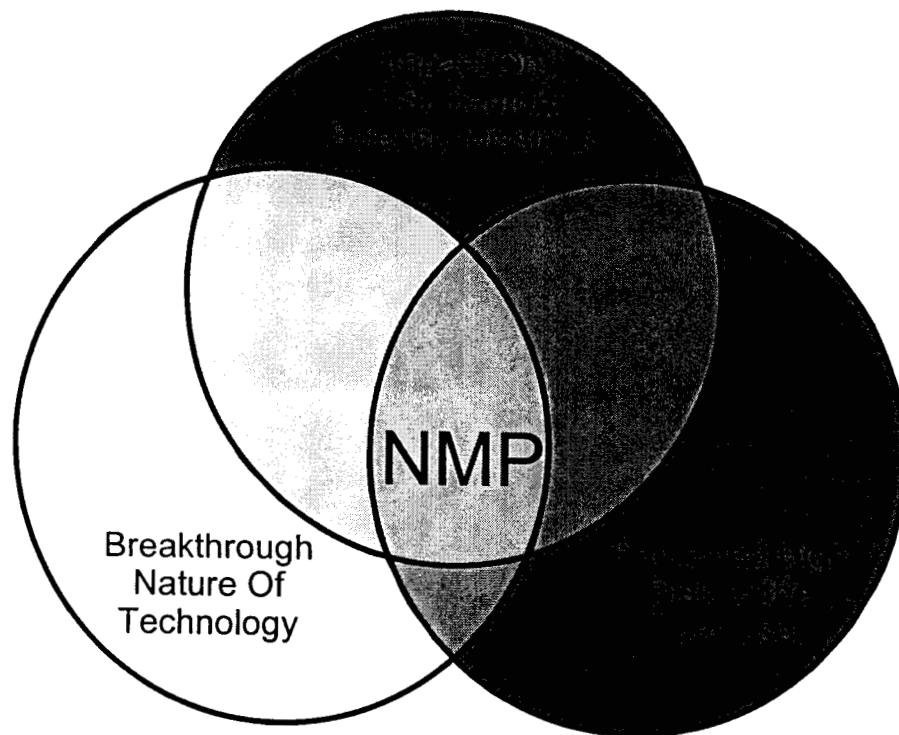




# The New Millennium Program



NMP is a cross-Enterprise program that identifies and flight validates breakthrough technologies that will significantly benefit future Space Science and Earth Science missions



- Breakthrough technologies
  - Enable new capabilities to meet Earth and Space Science needs
  - Reduce costs of future missions
- Flight validation
  - mitigates risks to first users
  - enables rapid technology infusion into future missions



# Background

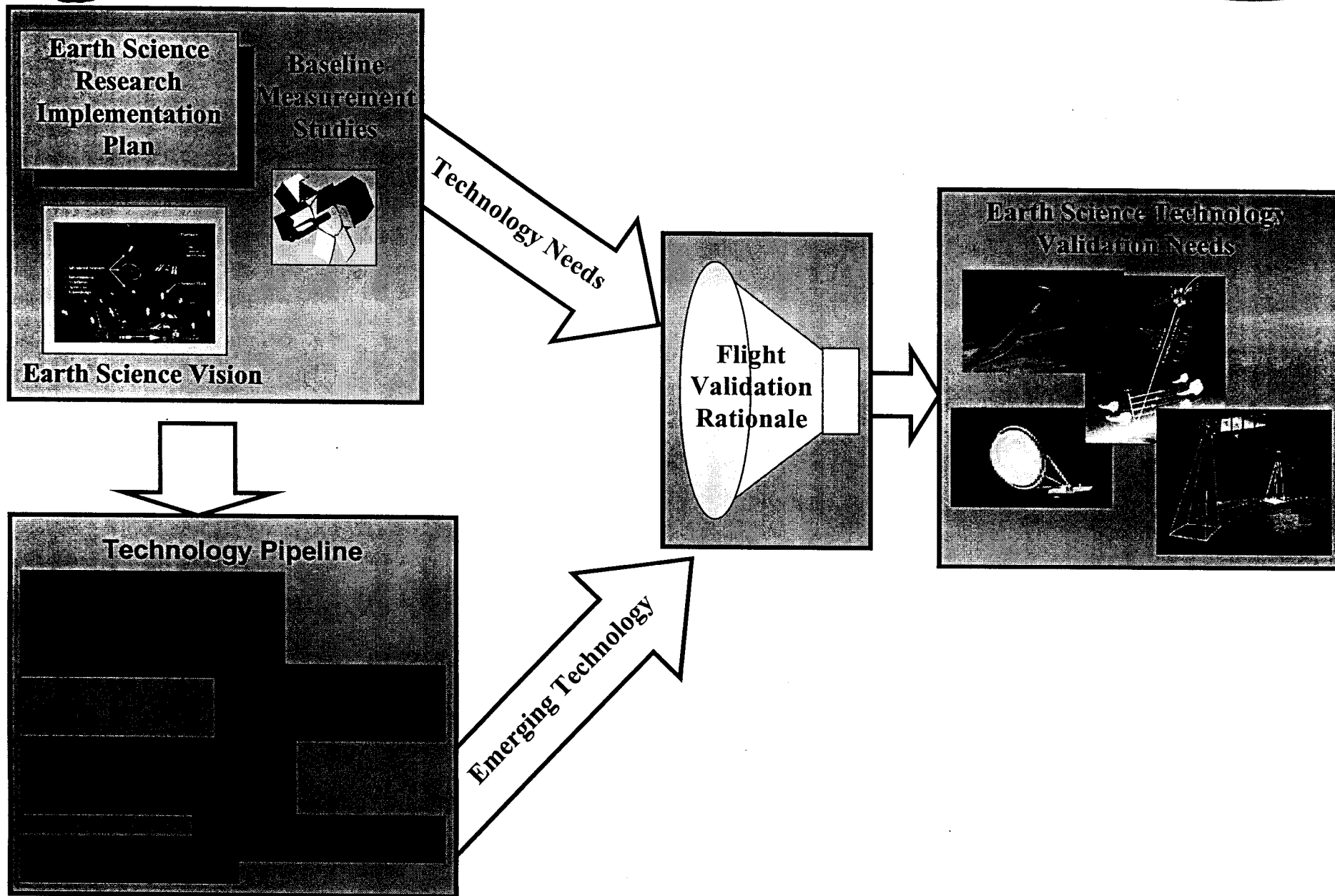


- NMP has initiated the process of identifying breakthrough spacecraft and instrument technologies and implementation approaches that
  - are needed to enable Earth Science Enterprise (ESE) missions with a planning time horizon of 5 to 15 years
  - require a validation in space to reduce their cost and risk to the first science user
- A strawman list of key component technologies was derived from existing ESE science planning documents
  - ESE Strategic Plan, Earth Science Implementation Plan, Easton Report
  - This list included
    - Large, Light-Weight Deployable Antennas
    - Light-Weight Deployable UV/Visible/IR Telescopes
    - Ultra-High Data Rate Communications
    - Intelligent Distributed Spacecraft Infrastructure
    - High Performance Spectroscopy
- This list of candidate technologies was presented to the ESE Associate Administrator for his review and concurrence



# ESE Technology Validation Needs

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# ESE Science Objectives

- Earth Science Enterprise Science Themes
  - Biology and Biogeochemistry of Ecosystems and the Carbon Cycle
  - Global Water and Energy Cycle
  - Climate Variability and Prediction
  - Atmospheric Chemistry
  - Solid Earth Science
  
- Types of research tools for each Program
  - Global systematic measurements
  - Exploratory or Process-Research satellite missions
  - Field studies and supporting laboratory research
  - Data and information systems



# Examples of Emerging Technologies: Potential IIP Flight Validation Candidates



*A Second generation Spaceborne Precipitation Radar (PR-2)*



## Technology area

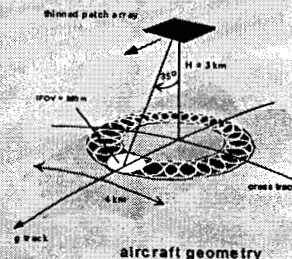
5.3 meter dual-frequency(13.6 & 35 Ghz) lightweight (100 Kg) inflatable antenna

## Flight Validation Rationale

Test the stability and antenna pattern of a large, light weight inflatable structure for 35 Ghz frequency, 600 KM swath at 2 Km resolution.

Inflatable Antenna

*Two Dimensional Synthetic Aperture Radiometer for Microwave Remote Sensing from Space*



## Technology area

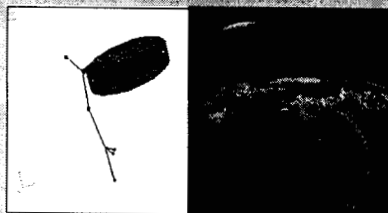
6X10 meter deployable thin array antenna  
Small digital correlators

## Flight Validation Rationale

Validate the thin array antenna concept  
Verify structural and thermal stability  
Verify two-dimensional aperture synthesis concept

Large/lightweight Deployable Antenna

*Spaceborne Microwave Instrument for High Resolution Remote Sensing Using a Large Aperture Mesh Antenna*



## Technology area

6-meter aperture deployable mesh reflector

## Flight Validation Rationale

Validate stability of mesh reflector

Deployable Mesh Antenna

*Active Tropospheric Ozone and Moisture Sounder (ATOMS)*



## Technology area

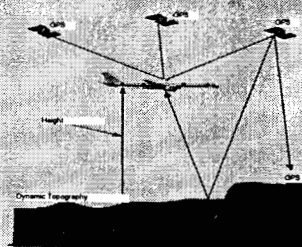
10,22, and 183 GHz links for moisture sounding from 0~20 km 110 and 165 GHz links for ozone sounding from 8km ~60 km

## Flight Validation Rationale

Validate control infrastructure needed for monitoring, controlling, and orbit maintenance of a constellation of small satellites

Constellation of Small Satellites

*GPS-Based Oceanographic and Atmospheric Low Earth Orbiting Sensor (GOALS)*



## Technology area

Performing surface altimetry using GPS reflections

## Flight Validation Rationale

Validate new measurement concept of an on-going measurement

Measurement Technique Using Constellation of Satellites

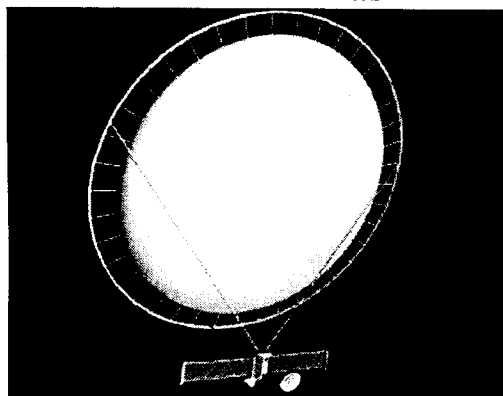


# Emerging Technology Subsystem Themes

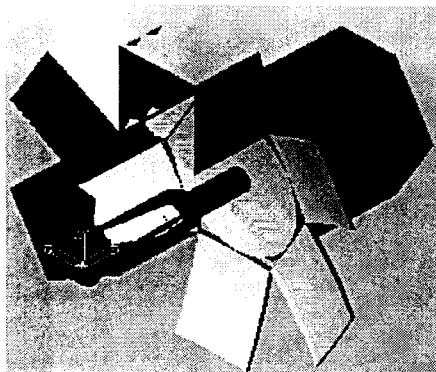


- Several recurring technology subsystem validation “themes” have emerged
- Each technology “theme” benefits a broad set of Earth Science measurements.

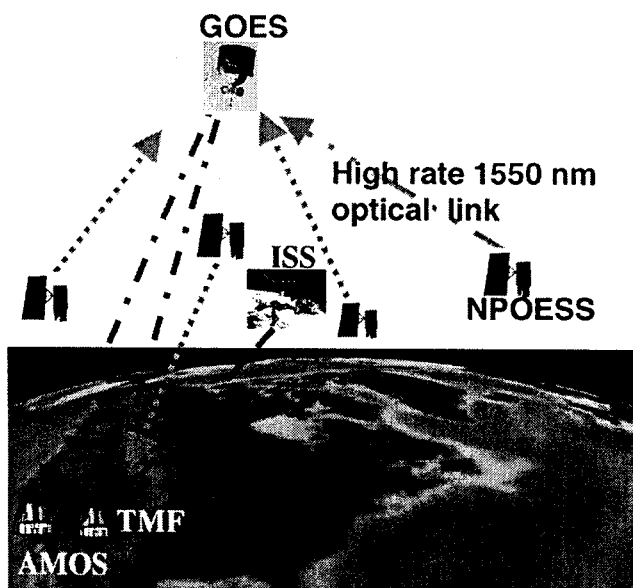
**Large Deployable  
Microwave/ Millimeter  
Wave Antennas**



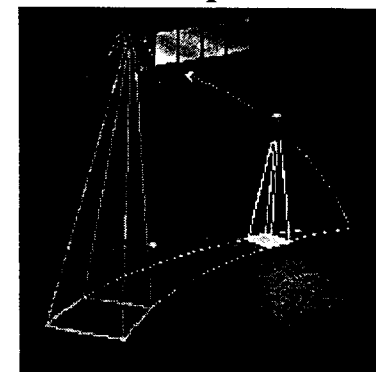
**Gossamer Deployable  
Visible/IR Optics**



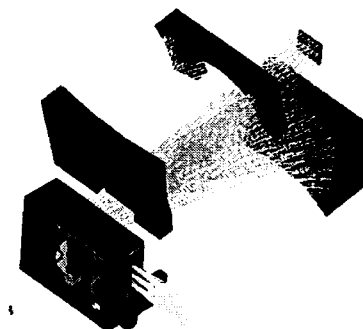
**Ultra-High Data Rate Communications**



**Autonomous Constellation  
Control/Operation**



**High Performance Spectrometry**





# Large Deployable Microwave and Millimeter Antennas

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## Component Technologies

### Space Inflatable Structures, (TRL 5)

- System architecture
- Deployment control
- Dynamic analysis and simulation
- Scaling laws and ground testing

0 g for  
deployment  
& performance

### Rigidization in Space, (TRL 4)

- Low or no power requirements
- Low or no contamination

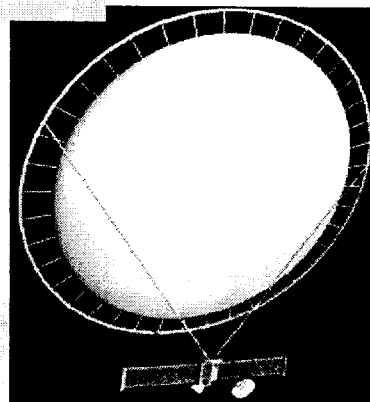
0 g,  
Vacuum &  
Extreme Temp

### Long-Term Space Survivability, (TRL 4)

- Materials characterization
- Degradation effects of space environment
- >5 year survivability

### Membrane Compatible Electronics (TRL 3-4)

- Multi-layer RF membrane microstrip array aperture
- (L-band, 80 MHz bandwidth, dual-polarization)
- High frequency membrane reflector and reflect arrays
- (Ku-band, Ka-band, W-band)
- MEMS T/R Module
- Thin-film solar array



Radiation,  
Atomic O &  
Micrometeoroid

## Measurement Approach

- Altimeter
- Scatterometer
- Synthetic Aperture Radar
- Clouds/Rain Radar

## Science Needs

- Soil Moisture & Ocean Salinity
- Carbon Cycle & Biomass Budget
- Topography & Natural Hazards
- Ocean Surface Wind & Topography
- Land Surface Water & Ice Sheet Monitoring
- Global Climate Modeling & Precipitation

MISSIONS

EOS 3467

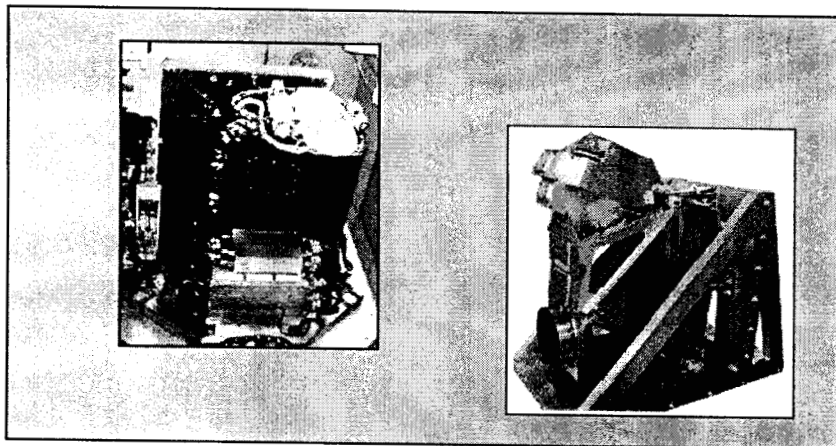
EX 56



# Augment NMP Program with Enabling Breakthrough Subsystems



## Integrated Measurement System

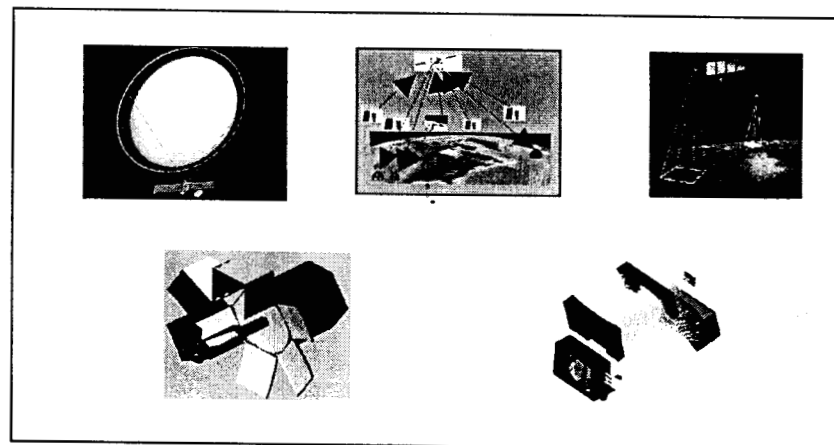


- Paradigm shift in measurement approach
  - Validation to ensure critical measurement continuity
- Risk validation required for operational transition

## Sharpen Current NMP Criteria

- Balanced mix of subsystem/integrated measurement systems

## Breakthrough Subsystems



- Breakthrough subsystems that
  - Require flight validation (environment, radical paradigm shift)
  - Enables critical functions for key/enhanced measurements
  - Broad benefits to multiple measurement systems
- Breakthrough subsystems can be tested as stand-alone items without full instruments



# Workshop Objectives



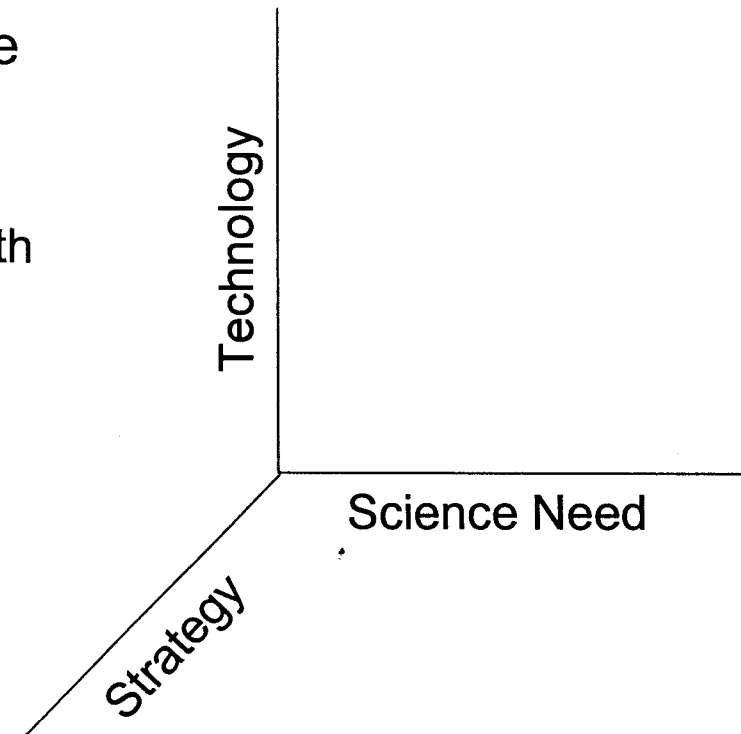
- Clarify the relevance of each class of technologies for future ESE science mission objectives
  - new science investigations enabled by technologies
    - new measurement type
    - improved spatial, temporal, or spectral resolution or sampling
    - new vantage points (MEO, GEO, L1, L2)
  - anticipated time scale for science mission
- Identify specific technology solutions that address these needs
  - current state of the art
  - capabilities enabled by new technology
  - current Technology Readiness Level (TRL)
  - ongoing technology development
- Requirements for flight validation
  - justification
  - objectives, scope, and milestones
  - top-level validation flight development schedule
- Refine materials for NMP presentation to the ESE AA



# Workshop Approach



- Convene a 1-day mini workshop in each of the 5 technology areas
- Encourage interactions between the ESE science and technology communities by inviting
  - 5 to 6 scientists who are familiar with ESE science plans
  - 5 to 6 technologists who are knowledgeable about evolving capabilities
- Each workshop will also include participation by
  - the New Millennium Program
  - NASA HQ
  - other interested parties







# Defining the State of the Art: Technology Readiness Levels

- TRL 1 Basic principles observed and reported
- TRL 2 Technology concept and/or application formulated
- TRL 3 Analytical and experimental critical function and/or characteristic proof-of-concept
- TRL 4 Component and/or breadboard validation in laboratory environment
- TRL 5 Component and/or breadboard validation in relevant environment
- TRL 6 System/subsystem model or prototype demonstration in a relevant environment (ground or space)
- TRL 7 System prototype demonstration in a space environment
- TRL 8 Actual system completed and "flight qualified" through test and demonstration (ground or space)
- TRL 9 Actual system "flight proven" through successful mission operations



# Flight Validation Justification for Breakthrough Technologies



FACTORS	SUB-FACTORS	EXAMPLE EFFECTS	EXAMPLE JUSTIFICATION
<b>1. SPACE ENVIRONMENT</b>  (Ground Test Impossible)	<b>1.1 Persistent Effects</b> are steady space/planetary environments acting on the technology.	Zero Gravity, Radiation Effects, Noise Sources, Temperature cycling.	Large, light-weight deployable structures need zero G flight validation because an accurate ground test is impossible.
	<b>1.2 Transient Effects</b> are impulse space/planetary environments acting on technology.	Cosmic Rays, Temperature spike, Particle and Fields, Noise, Microphonics	System level faults, such as cosmic-ray induced single-event upsets in integrated circuits. Validation flight needed to confirm software error handlers.
	<b>1.3 External Interactions</b> are environments used by the technology to accomplish something.	Cometary Surfaces, Planetary Atmospheres, Solar Wind.	Aeroassist technologies using planetary atmospheres and solar sails using solar wind for propulsion. Both require flight validation to build an experience base and to determine the performance envelope and operating safety margins.
	<b>1.4 Reliability Hazards</b> are space/planetary environments that degrade performance.	Micrometeorite, Dust Accumulation, Atomic Oxygen, Radiation Effects.	Micrometeorite, orbital debris, dust accumulation, atomic oxygen, and radiation effects are difficult to predict and simulate.
<b>2. MAJOR IMPLEMENTATION SHIFT</b>  (Never Flown Before)	<b>2.1 Fundamental Change</b> is a revolutionary way of designing, assembling, fabricating, testing, integrating, or operating.	Revolution in Design Procedures or Operations.	Multifunctional structures invoke new assembly, test and rework procedures that depart from existing practice and require flight validation to verify procedures and demonstrate flight worthiness.
	<b>2.2 Combined Effects</b> are complex interactions between advanced technology and different parts of the system or launch vehicle.	Contamination, Noise Sources, Survivability, Ionic Contamination, Launch Debris.	Contamination, deposited by thrusters or other sources, is difficult to predict; thus, flight validation needed to confirm contamination models.



# The Flight Validation Plan



## 1. DESCRIPTION

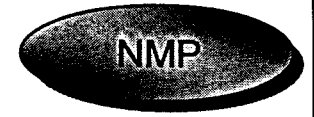
- Overview:
  - General description of the technology.
  - Resource requirements in terms of the mass, volume, power, and data rate.
  - Identify the technology as a component, subsystem or system.
- Functionality: Describe how the technology performs.
- Experimental Approach: For example, explain the experimental set-up as:
  - Dependent on other technologies (e.g. side-by-side experiments)
  - Not dependent on other technologies (e.g. stand alone experiments)
  - Needs diagnostic sensors
    - Data Acquisition: Describe the data rate, volume, and sequence

## 2. PERFORMANCE EVALUATION:

- Test Metrics/Data Products:
- Test Location: Discuss differences between the following:
  - Ground
  - Pre-Flight
  - In-Flight
- Test for Reliability: Discuss failure modes and the approach to their characterization.
- Test Environment ( noise, contamination, and radiation):
  - NMP Flight Environment
  - End-Use Environment:



# The Flight Validation Plan (continued)



3. RISK REDUCTION: Discuss the risk factors that will be reduced thus, enable the use of the technology.

- Risk Factors:

- Maturity
- Manufacture
- Replication
- Interactions
- Accommodation
- Test
- Cost

4. TECHNOLOGY INFUSION: Describe how progress will be communicated to the user community.



# Developing a Flight Validation Rational



## Criterion 1 Applicability to the NASA OES Science Measurements

- concept's potential contribution to NASA's scientific areas of emphasis.
  - Science mission themes supported
  - Specific missions supported
- Is the concept a breakthrough, and are the technologies revolutionary?
  - The anticipated benefits of the proposed technique versus existing or currently planned sensors.
  - The potential of the measurement technique to evolve, once validated, into an operational instrument.
  - Does the concept enable a new measurement(s)?
  - Is there a plan for infusing the advanced technologies into the U.S. R&D industrial base?

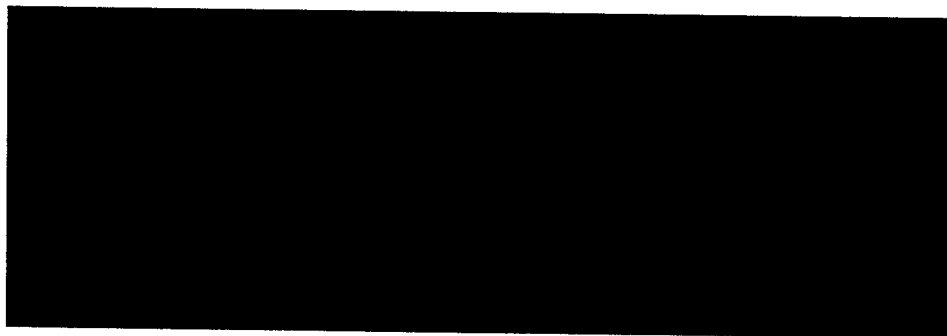


# Developing a Flight Validation Rational (continued)



## Criterion 2 Maturity of the Concept

- Demonstrate that the measurement concept payload is at an appropriate level of readiness that it can be delivered for integration onto a spacecraft or carrier by required date.
  - Document current TRL Level
  - Identify ongoing technology development efforts
- Justify why the technology requires-on orbit flight validation.
- Feasibility of obtaining the required measurement with the proposed concept.





# Requirements for Large Deployable Microwave and Millimeter Antennas

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## Science / Measurement

### Requirements

- Altimeters
  - horizontal/vertical resolution
- Scatterometers
- Synthetic Aperture Radar
- Cloud/Rain Radar

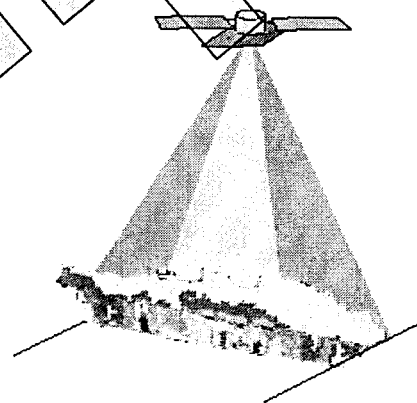
### Relevance to Future ESE Missions

- Soil Moisture & Ocean Salinity
- Carbon Cycle & Biomass Budget
- Topography & Natural Hazards
- Ocean Surface Wind & Topography
- Land Surface Water & Ice Sheet Monitoring
- Global Cloud Mapping & Precipitation
- Severe Storm Monitoring

## Description of Technology

- 5.3 meter dual-frequency (13.6 & 35 GHz) lightweight (100 Kg) inflatable antenna
- 6X10 meter deployable thin array antenna, Small digital correlators
- 6-meter aperture deployable mesh reflector

## Illustration of Technology





# State of the Art for Large Deployable Microwave and Millimeter Antennas

NMP

## Description of the state of the art for the Technology

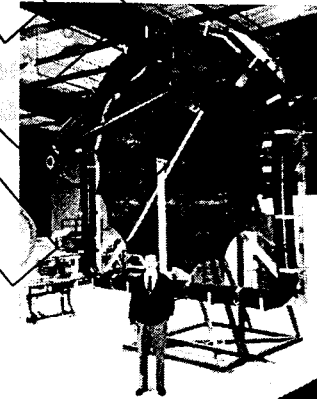
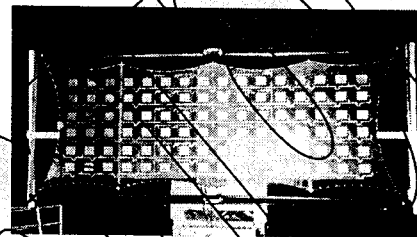
- Space Inflatable Structures, (TRL 5)
- Rigidization in Space, (TRL 4)
- Long-Term Space Survivability, (TRL 4)

## Major Technology Elements and TRL

- **Space Inflatable Structures**
  - System architecture
  - Deployment control
  - Dynamic analysis and simulation
  - Scaling laws and ground testing
- **Rigidization in Space**
  - Low or no power requirements
  - Low or no contamination
- **Long-Term Space Survivability**
  - Materials characterization
  - Degradation effects of space environment
  - >5 year survivability

## Illustration of State of the Art

3.3m x 1m L-band SAR radar array



3m Ka-band telecom reflectarray

## Technology Development Roadmap

- FY 2001 Pre-launch packaging studies
  - identify candidate flights of opportunity
  - materials, packaging and deployment hardware for validation flight
- FY 2002-2004: Validation Flight Implementation
- FY 2004: Validation Flight



# Validation Plans for Large Deployable Microwave and Millimeter Antennas

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## Description/Justification of Proposed Space Validation

- Demonstrate deployment in zero-g
- Demonstrate optical surface figure / quality
  - thermal effects
  - atomic oxygen
- RF performance and stability and antenna pattern

## Expected Benefits

- Accelerate infusion of large, low mass antenna with small storage volume
- Reduce real and perceived risk
  - deployment
  - rigidization/stability/lifetime
  - RF performance
  - Control of large, light-weight structure (drag, moment arm...)

## Projected Cost and WF by FY

	FY 01	02	03	04	05
\$M	2	6	12	15	7
WY	5	12	14	20	10

## Top-Level Development and Flight Schedule

- Validation Flight Formulation: FY 2001
- Validation Flight Implementation: FY 2002-2004.
- Validation Flight Operations: FY 2005
- Science Mission Formulation: 2006-2008
- Science Mission Operations: 2009 ...



# Follow-on Planning Activities for Large Deployable Microwave and Millimeter Antennas

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## Future Feasibility Studies

- System vs Component flight validation trades
  - Benefits/Risks
- Partners/Launch opportunities
- Special instruments needed for validation (cameras to monitor deployment, surface quality, etc.)

## Justification

- Some system-level issues may compromise value of a component-level demonstration
  - platform pointing/stability might affect ability to validate system
- For component validation, must insure that problems in deployment of large gossamer structure do not compromise partner's mission

## Projected Cost and WF By FY

FY 01  
\$M  
WY

	Q1	Q2
\$M	.05	.05
WY	0.3	0.3

## Top-Level Schedule

- Study Phase: 10/00 - 3/01



# Summary and Recommended Next Steps



- Initiated identification of technology validation needs for Earth Science
  - Initiated mini-workshops to refine
    - capability needs
    - candidate technological solutions
    - candidate technology validation flights
  - Finalizing materials for presentation to ESE AA
- Recommended next steps
  - Solicit input for broader segments of the the science and technology communities
    - validate capability needs
    - conduct focused trade studies
      - 3 month topical studies will be recommended to ESE
  - Assess breakthrough subsystem validation requirements/approaches
    - ESTO/NMP team
    - Status review/feedback sessions with ESE (YS/YO)
    - Presentation in May '00 to the ESE AA
  - Synthesize technology investment advocacy package